

## **Sodium Titanate Anodes for Dual Intercalation Batteries**

Lithium supply security issues and the increasing need to develop low-cost large battery systems for grid storage applications have driven the recent interest in sodium-ion batteries. These devices operate much like the better-established lithium-ion analogs, except that sodium ions shuttle between the anode and cathode rather than lithium ions. New materials are needed for the sodium systems, in particular for the anode, because graphite (the most common anode material for Li-ion systems) does not intercalate sodium. Alternatives such as alloys and hard carbons are being investigated for this purpose, but cyclability in the first case, and safety, in the second case are issues. The best choices for the near term are insertion electrodes based on sodium titanates, which are low-cost, made from earth-abundant precursors, and have low toxicity. In the Na-Ti-O system, several different tunnel or stepped-layered structures can be made depending on synthesis conditions, the presence or absence of quaternary elements, and Na/Ti ratios. Some of these compounds exhibit both reversible sodium and lithium intercalation behavior with high capacities. Of particular interest are electrodes based on “sodium nonatitanate”, a stepped layered compound used for nuclear waste clean-up, and lepidocrocite-structured titanates. The theoretical capacities of these electrodes are high (>200 mAh/g) and they exhibit solid solution behavior upon insertion of lithium or sodium at very low average potentials (0.5-0.3V vs.  $\text{Na}^+/\text{Na}$  or  $\text{Li}^+/\text{Li}$ ). These characteristics imply that high specific energies could be achieved in either sodium-ion or lithium-ion batteries that utilize them as anodes, once they are fully optimized. A particularly interesting feature of the lepidocrocite-type titanates is the cooperative co-

insertion and de-insertion of solvent along with alkali metal cations during electrochemical cycling. The replacement of alkali metal cations with solvent molecules during charge and *vice versa* during discharge means that there is almost no volume change during cycling over a wide composition range, resulting in excellent capacity retention.

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**Biography**

Marca M. Doeff is a staff scientist at Lawrence Berkeley National Laboratory and a principal investigator in several battery programs funded by the U.S. Department of Energy. She has co-authored more than 150 papers and abstracts on materials for lithium/polymer, lithium-ion, and sodium-ion batteries, and is currently treasurer of the Battery Division of the Electrochemical Society.